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Lead and other Metals in Riyadh Atmosphere and Its Relationship to Traffic Volume and Industrial Activities

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The concentrations of Pb, Zn, Cu, Cd, Cr and Ni in atmospheric particulates have been determined at nine main roads and the three industrial locations (first industrial city, second industrial city and the industrial workshops area) in Riyadh city. The experimental results obtained, show that the automobile emission is the predominant source for Pb, Zn, Cu and Cd pollution along the main roads. A relation between the traffic flow and the level of lead pollution was observed. The highest lead concentration was observed at King Fahad road and the industrial workshops area (3.60 and 3.30 μg m^{-3} respectively), which is higher than the European community (EC) limit (2 μg m^{-3}). The highest concentrations of Zn, Cu, Cd, Cr and Ni were recorded at the industrial workshops area, which shows to be one of the main sources of these metal pollutants in Riyadh city.

Key Words: Pb, Zn, Cu, Cd, Cr, Ni, Atmospheric particulate, Riyadh, Saudi-Arabia

INTRODUCTION

Lead concentrations have been considerably elevated by human impact even in remote sites. This is supported by the high enrichment factors, *e.g.*, 290 in south Indian ocean and 3,500 at south pole[1]. The natural background concentration of lead from purely geochemical sources in unpolluted atmospheres has been estimated to be 0.0005 μg m^{-3}.[2] In an attempt to determine present-day baseline concentrations for continental United States, the annual average lead aerosol concentration was found to be 0.008 μg m^{-3} in 1971 at white mountain (elevation 3800 m) north of Bishop, California with a seasonal variation ranging from 0.0012 to 0.029 μg m^{-3}.[3]

The CEC has adopted the proposal that 2 μg m^{-3} is used by member nations as a limit for the annual average level for Pb in urban areas. The WHO guideline for Pb concentrations is more stringent than that of the CEC and has been set at 0.5 to 1.0 μg m^{-3}.[4]

Atmospheric Pb arises mainly from the emission of automobile exhausts and certain industrial processes and to a lesser extent from coal combustion and weathering of paints[5]. The concentration of airborne Pb resulting from the use of leaded petrol depends on factors such as traffic density, traffic speed, weather conditions and local topography.

The concentration of airborne Pb also decreases rapidly with distance from roads; for example, a concentration of 5.4 μg Pb m^{-3} found at 3 m distance from Cairo-Alexandria road in Egypt dropped to 2.3 μg Pb m^{-3} at 40 m from the road[6]. In addition, the total amount of Pb emitted to air from traffic varies in proportion to the total consumption of petrol and its lead content. In U.K. a rapid reduction in Pb emission occurred after January 1986, when the permissible Pb concentration in petrol was reduced from 0.4 to 0.15 g^{-1} and further reductions have occurred following the introduction of unleaded petrol[4].

Urban airborne Pb levels vary with the size of the city, traffic density and the size of population. The Pb content of air in European cities ranges from 0.4 to 4.8 $\mu g\ m^{-3}$.[7] In U.S.A., Schroeder *et al.*[8] reviewed the metal pollution in 58 cities and 29 non-urban areas. All cities and all non-urban areas but Yellowstone park had Pb in the air. Lead levels in cities ranged from 0.1 to 2.3 $\mu g\ m^{-3}$. The largest amounts occurred in Burbank, Calif, Ashland, Ky, Indianapolis and New York city, each with more than 1.0 $\mu g\ m^{-3}$. Even non-urban Pb varied from 0.0014 to 0.15 $\mu g\ m^{-3}$, overlapping the range in cities. In Cairo, the highest concentration of Pb was 2.5 $\mu g\ m^{-3}$ found in the central district, and even the residential district was found to be highly polluted with a lead concentration of 1.3 $\mu g\ m^{-3}$.[9]

In U.K., Lee *et al.*[4] reported the mean air Pb concentrations at urban sites to range from 0.3 to 1.3 $\mu g\ m^{-3}$ over the period 1970 to 1989, the highest mean concentrations by far occurring at a site situated close to a smelter. The mean concentrations of Pb at two rural sites were *c.* 0.05 $\mu g\ m^{-3}$ (Windermere) and 0.10 $\mu g\ m^{-3}$ (Chilton). In India, automobile emissions were found to be the predominant source of Pb pollution in the atmosphere of Varanasi city with an average concentration of 0.30 $\mu g\ m^{-3}$.[10]

It is also recognized that in addition to Pb, other metallic pollutants such as Cu, Zn, Ni, Cr and Cd are present in elevated quantities in the atmosphere adjacent to roads and industrial areas (Muskett and Jones[11]; Nasralla and Ali[9]; Warren and Brich[12]; Harrop *et al.*[13]; Tripathi[10]; Lee *et al.*[4]).

Being located in a very arid zone surrounded by vast desert areas, Riyadh city is suffering from serious particulate pollution problems. During wind storms tremendous amounts of dust are usually picked up from the surface of the neighbouring desert and transported to the city. El-Shobokshy[14] found the accumulation rate of dust on Riyadh to be 668.4 tonnes km^{-2} $year^{-1}$ and suspended particulates to be 500 $\mu g\ m^{-3}$, which exceed the WHO limits of 108 tonnes km^{-2} $year^{-1}$ and 76 $\mu g\ m^{-3}$ respectively[15]. In addition, El-Shobokshy *et al.*[16] found total inhalable particulates in Riyadh to be 640 $\mu g\ m^{-3}$. All kinds of activities involved in Riyadh's exceptional development have led to increases in various types of pollutants, including heavy metals. Automobiles are considered to be the principal contributor to air pollution, particularly Pb. Of the total automobile emissions of 416×10^3 tons in the country in 1984, Riyadh accounted for about 30% (nearly 125×10^3 tons $year^{-1}$)[17].

With a Pb content of 0.60 $g\ L^{-1}$ of gasoline, Saudi Arabia is among the countries using the maximum content of Pb in motor gasoline. Naturally, this will have a major impact on the Pb level in the atmosphere of the country, especially in urban areas.

In Riyadh city heavy metals in suspended dust has been evaluated by only a few studies. In 1983, El-Sahaf[18] has evaluated some atmospheric pollutants in seven places in Riyadh city. Average concentrations of some atmospheric pollutants in seven places in Riyadh city by El-Sahaf[18] are presented in Table-1.

TABLE-1
CONCENTRATIONS OF AIR POLLUTANTS IN DIFFERENT AREAS IN RIYADH ($\mu g\ m^{-3}$) (AFTER EL-SAHAF, 1983, Ref. 18)

Location	Ni	Cu	Zn	Pb
Apip/Rafa area (W)	0.04	1.01	0.11	4.09
Old airport road (C)	0.03	0.24	0.11	1.54
Al-Takhsisi road (W)	0.02	10.29	0.04	—
Old airport (N)	0.02	1.25	0.21	1.54
Ministries area (C)	0.03	2.91	0.16	1.81
Industrial area (SE)	0.04	1.84	0.62	1.93
Girl's college (NE)	0.03	0.04	0.12	1.32

El-Shobokshy[19] investigated the inhalable particulate Pb in the ambient atmosphere of Riyadh, and showed that the average concentration of Pb during the working days is 2.79–3.83 $\mu g\ m^{-3}$, up to twice the international standard. Lead pollution levels were measured near to two schools in Riyadh by El-Shobokshy[20]. One in the city centre and the other in a suburban area had average Pb concentrations in the atmosphere of 5.5 and 2.5 $\mu g\ m^{-3}$ respectively. It was concluded that the city centre is suffering from high Pb pollution level, which may reach as high as 9 $\mu g\ m^{-3}$ during winter months due to traffic density and pockets of atmospheric stagnation.

In Riyadh city there are two industrial cities for light industries, the first located near the city center with a total area of 541000 m^2 and 59 factories and the second located 17.5 km south-east of the center of the city, with a total area of 12,000,000 m^2 and 497 factories. A further industrial area, located near the city center bounded on the north by the first industrial city, covers an area of about 1,800,000 m^2. This industrial area contains hundreds of privately owned workshops engaged in welding, metalwork, car repairs, painting, etc. Emissions from these, plus the numerous and densely distributed motor vehicles and pollution from a petroleum refinery and a cement factory, coupled with high temperatures, lack of rain and mainly low wind speeds lead to the accumulation of air pollutants over the city. The situation is exacerbated by dust-laden wind, especially during dust storms blowing mainly during spring and autumn.

The objective of this investigation was to measure the concentration of heavy metal pollutants in the atmosphere of the main roads and industrial locations in Riyadh city.

EXPERIMENTAL

Sampling and samples treatment

Air samples were collected using portable high volume dust samplers (Rotheroe & Mitchell L30: flow rate 35 L min^{-1}) during a sampling period of 24 h. Air sampling was performed at eight main roads varying in traffic density and from the first industrial city, the second industrial city and the industrial workshops area. From all locations air samples were collected at 1.5 m above the ground, by drawing air through a cellulose filter (Whatman No. 41). Whatman No. 41 filters were chosen because firstly these are the most widely used filter papers of this type for air sampling[21], secondly, they have low trace elemental impurities and are cheap and simple to use[22]. Each filter was carefully transferred from the monitoring head into a clean, labelled, self-sealing, plastic bag.

Extraction method

In the laboratory, the filters were transferred to 50 mL acid washed beakers, 10 mL of concentrated HNO_3 (BDH AnalaR) was added, and the samples were digested at 100°C using a hot plate to near dryness. When cool, the samples were centrifuged and made up to volume with 1% HNO_3 (BDH AnalaR). Blanks for the reagents and filter papers were obtained by digesting unused filter papers in the same way as the samples.

Element concentrations were measured by an atomic absorption spectrophotometer (Perkin-Elmer model 1100, micro-computer controlled with integrated CRT screen and keyboard function). The precision of the results was checked by duplicating 20% of the samples chosen randomly. In order to ascertain the accuracy of the method employed, two reference materials were included with every batch (SRM 1547 Peach leaves and CRM 281 Rye grass).

RESULTS AND DISCUSSION

Heavy metals in roadside atmosphere

Metal concentrations in air samples collected from the roadside are shown in Table 2 and Fig. 1. Lead in the atmosphere is derived principally from the

TABLE-2

METAL CONCENTRATIONS (mg/m^3) IN AIR COLLECTED FROM ROADS AND HIGHWAYS IN RIYADH CITY

Location	Pb	Zn	Cu	Cr	Ni	Cd
Ring road (East)	1.806	0.097	0.051	0.069	0.114	0.034
S.A. Rahman road	0.391	0.066	0.030	0.060	0.102	0.027
A.Sibn Aziz road	0.554	0.032	0.025	0.036	0.064	0.021
Aibn Abdulaziz road	0.663	0.034	0.030	0.034	0.071	0.025
Makkah road	1.803	0.090	0.032	0.036	0.061	0.029
King Fahad road	3.602	0.095	0.060	0.034	0.046	0.042
Ring road (South)	1.381	0.046	0.026	0.038	0.059	0.022
Alkarj road	1.251	0.033	0.076	0.037	0.048	0.023
Average	1.431	0.062	0.041	0.043	0.071	0.028
Rural area	0.280	0.032	0.021	0.023	0.030	0.010

combustion of petrol containing Pb additives. Lead is added to petrol as an "anti-knock" agent in the form of tetra-alkyl lead. The airborne Pb concentrations were significantly lower in low density traffic roads compared with those in high density traffic roads. The highest concentration of 3.60 $\mu g\ m^{-3}$ was recorded at

King Fahad road, with the highest traffic volume among the investigated roads (9900 cars/h). This concentration is considerably higher than the European Economic Community[23] and USEPA[24] permissible levels (2 μg m^{-3} and 1.5 μg m^{-3}, respectively). The airborne Pb levels at the eastern section of the Ring road and Makkah road were similar (1.80 μg m^{-3}), which is higher than the USEPA permissible level (1.5 μg m^{-3}). The levels of airborne Pb at the other studied roads were below the (EEC) and (USEPA) maximum acceptable level of Pb, but they were all higher than Pb level at the rural (control) area (0.28 μg m^{-3}).

Zinc originates principally from smelting operations, coal combustion, incineration and wood combustion[25], from the wearing down of vehicle tyres[13, 26] and

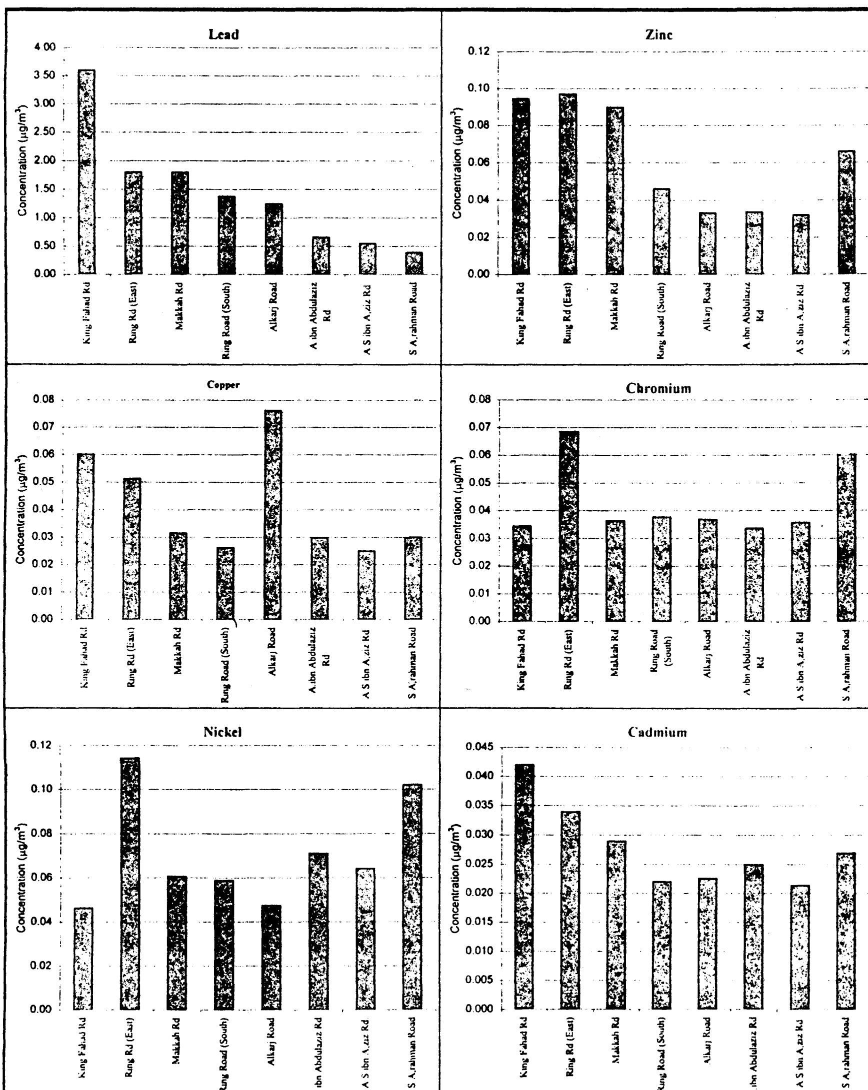

Fig. 1. Metal levels in air (μg/m^3) in roads and highways in Riyadh city.

is generally present in small particles, less than 1 μm in size[27, 28]. Since Zn is an important component of some lubricating oils and is present in motor vehicle tyres[29], its levels in the roads atmosphere showed similar trends to those of Pb emitted from automobile exhausts (Fig. 1). The highest concentrations were recorded at King Fahad road, Ring road (East) and Makkah road (0.095; 0.097 and 0.090 μg m^{-3} respectively), which is three times higher than the rural (control) area (0.032 μg m^{-3}).

Copper is a common constituent of piping and other components of engines[30]. The highest concentration was recorded at Alkarj Road (0.76 μg m^{-3}), which can be attributed to the different industrial activities bordering this road. King Fahad road and Ring road (East) show high copper concentrations (0.060 and 0.051 μg m^{-3}) compared to the rural (control) area (0.021 μg m^{-3}).

Cadmium originates from smelters, fuel combustion, paint and plastics manufacturing and volcanoes[25, 31]. It has been reported as a constituent of car tyres[29, 32]. Cadmium levels in the roads atmosphere showed similar trends to those of Pb emitted from automobile exhausts (Fig. 1). The highest concentrations were recorded at King Fahad road (0.042 μg m^{-3}) and Ring road (East) (0.034 μg m^{-3}).

Nickel in the atmosphere originates from the combustion of fossil fuels (particularly from oil), smelting, crustal sources and volcanoes[33]. It is added to fuel oils as a lubricant[34]. The highest concentration was recorded at Ring road (East) (0.114 μg m^{-3}).

Chromium originates from crustal sources, coal combustion and vegetation combustion[35]. Its levels in the road's atmosphere showed similar trends to those of nickel (Fig. 1). The highest concentration was recorded at Ring road (East) (0.069 μg m^{-3}).

Heavy metals in the atmosphere of the industrial locations

Metal concentrations in air samples collected from the three industrial locations are shown in Table-3 and Fig. 2. The highest concentrations of all the investigated metal pollutants were recorded at the industrial workshops area.

TABLE-3
METAL CONCENTRATIONS (μg/m^3) IN AIR OF THE INDUSTRIAL LOCATIONS IN RIYADH CITY

Location	Pb	Zn	Cu	Cr	Ni	Cd
Second industrial city	0.10 ± 0.01	0.10 ± 0.01	0.04 ± 0.00	0.05 ± 0.01	0.07 ± 0.01	0.01 ± 0.00
First industrial city	0.99 ± 0.58	0.50 ± 0.38	0.07 ± 0.03	0.07 ± 0.01	0.14 ± 0.01	0.04 ± 0.00
Industrial area	3.30 ± 0.45	1.14 ± 0.53	0.21 ± 0.08	0.20 ± 0.04	0.35 ± 0.08	0.13 ± 0.04

High airborne Pb concentration in the industrial workshops area (3.30 μg m^{-3}) is due to the concentration of workshops and narrowness of the local roads, which make it subject to very considerable traffic congestion, whereas the low

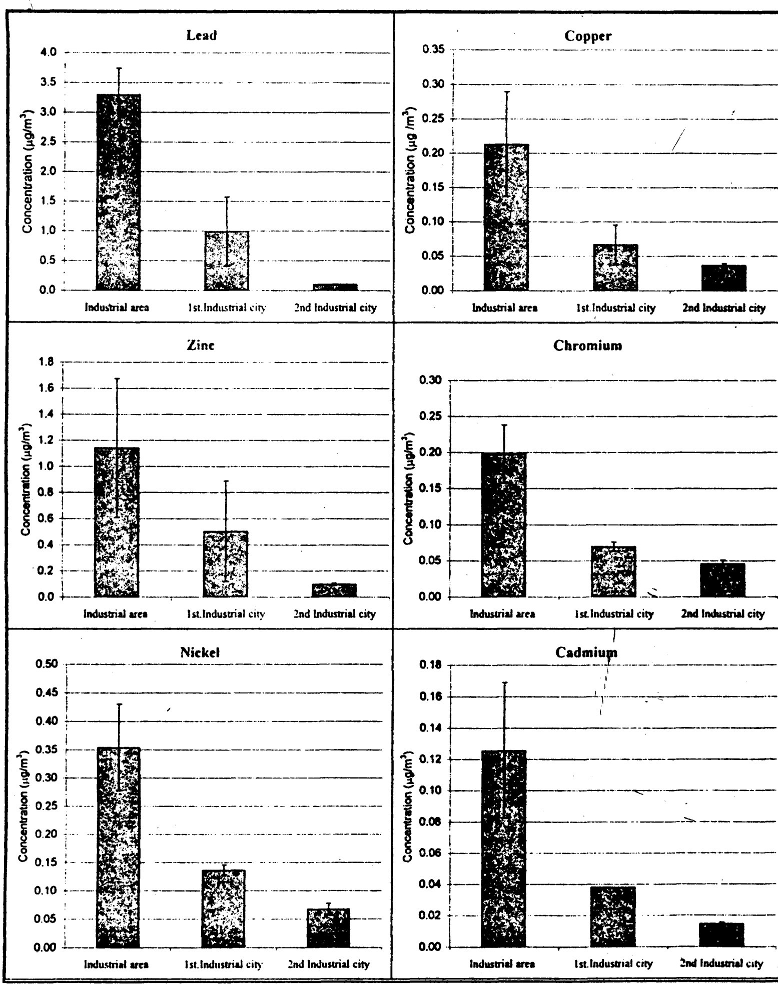

Fig. 2. Metal levels in air (μg m^{-3}) in the industrial locations in Riyadh city.

Pb levels recorded in the second industrial city (0.10 μg m^{-3}) is due to the large industrial plots, wide roads and less traffic. This indicates that automobile emission is the main source of atmospheric Pb in these locations.

Comparison of the Zn levels in the industrial locations with those in the roads environment and the rural (control) area shows that the industrial locations are clearly enriched in Zn. The industrial workshops area shows the highest mean Zn (1.14 μg m^3), followed by the first industrial city (0.50 μg m^3) and then the second industrial city with mean Zn level of 0.10 μg m^3. This indicates that Zn has an industrial source, such as metal smelting and galvanising processes.

The industrial workshops area shows the highest mean Cu level (0.21 μg m^3), which can be attributed to the metal processing taking place. The first industrial city shows a mean of 0.07 μg m^3, which can be attributed to metal smelting processes. Within the second industrial city concentrations of Cu were found to be higher than those determined from the rural area with a mean value of 0.04 µg m^3, which can be attributed to cables and lighting industries.

Levels of Cr, Ni and Cd in the first and second industrial cities were comparable to those recorded at the main roads in Riyadh city. But the levels of these metal pollutants in the industrial workshops area were significantly higher than those recorded at the main roads and the rural (control) area.

Effect of traffic volume on heavy metal in roads atmosphere

In general, the effect of traffic volume on the level of heavy metals is complex due to the effect of several other factors, such as age of the road and direction and speed of wind[36]. Nevertheless, in general, the larger the traffic volume the higher the amount of metal pollutants along the roads environment (Yassoglou *et al.*[37], Garcia and Killan[38] and Piron-Frenet *et al.*[39]). In this study there was a substantial difference between King Fahad road, corresponding to the highest traffic flow, and all other roads investigated. High correlation was found between traffic volume and Pb levels in roads atmosphere (Fig. 3). This result is in agreement with the findings of Daines *et al.*[40], Day *et al.*[41], and Warren and Birch[12]. Similarly, Ward *et al.*[42] found significant correlations between traffic density and Pb, Zn, Cu, Ni and Cr in roadside environment in New Zealand. This suggested that Pb contamination of roadside environment may be due to direct emission of Pb derived from vehicle exhausts, or the relocation of Pb deposited on road surfaces, or both.

In spite of the dependence of roadside metals on traffic, it appears from Fig. 1 that high concentration of one metal in roads environment does not necessarily mean that there will be high concentrations of other associated metals. Such variations are probably attributed to unaccounted variables such as road age, presence of local sources and the proportion of motor vehicles using diesel *vs.* leaded gasoline. Another important factor is the difference in particle size characteristics. The particle size of road traffic produced Pb has been determined

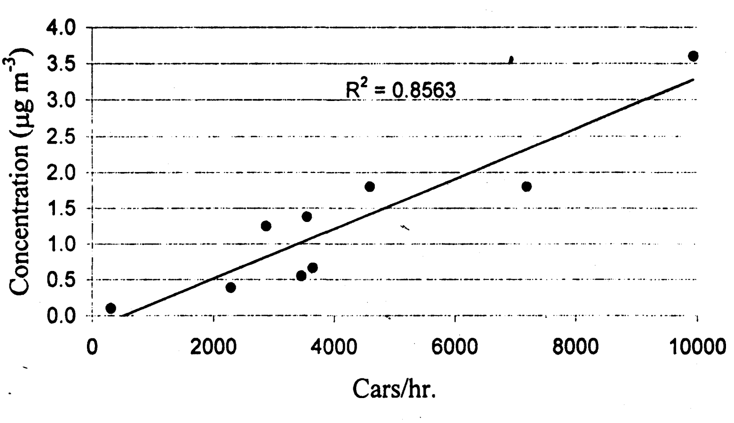

Fig. 3. Lead variation with traffic density in Riyadh city.

(Habibi[43]; Littlie and Wiffen[44]; Chamberlain *et al.*[45]) and found to be of extremely small sub-micron (approximately 0.02 μm) size, but there are apparently no studies which have evaluated the particle size characteristics of any other of the metals studied. As the sources of these metals are from different parts of the vehicle it is to be anticipated that the metals not subject to high thermal conditions, as is the case for Pb and Ni, are likely to have very different particle size characteristics. This affords a possible explanation for the variability in the variation between the metals investigated along roadside environment.

Interelemental correlation

The use of interelemental correlation can contribute to elucidating the common sources of the different metals. Strong correlations existed between Pb and Zn and Cd in roadside environment (70 and 85% respectively). From this result there can be no doubt that motor vehicle traffic is responsible for the buildup of all three heavy metals in roadside environment. The source of such Pb is obviously leaded gasoline, as has been so well established in the literature[30, 46–48]. Zinc has been attributed to the motor lubricating oils, car tyres and galvanised parts of vehicles such as galvanised tanks[30, 36, 42, 47]. Cadmium was attributed to the car tyres as well. The presence of these metals in the atmosphere along roadsides is probably due to mechanical wear and tear which deposits them as fine dust on the roadway and hence to the air. Strong correlation also existed between Ni and Cr (93%). Chromium is frequently used in chrome plating of some motor vehicle parts[30, 36], while Ni is added to fuel oils as a lubricant[34], indicating a crustal as well as motor vehicle origin of these two metals. Very strong correlations were found between all the metal pollutants in the industrial locations (99%), indicating industrial sources.

TABLE-4
AVERAGE LEAD CONCENTRATIONS IN SOME URBAN AND RURAL SITES

Location	Pb ($\mu g\ m^{-3}$)	References
Urban		
Bronx, New York, USA	1.58	Kleinman *et al.*[49]
Salamarca, Spain	0.14	Fidalgo *et al.*[32]
Antwerp, Belgium	0.11	Van Borm *et al.*[50]
Baghdad, Iraq	1.38	Kitto *et al.*[51]
Bahrain	0.66	Walter and Raveendran[52]
Dhahran, Saudi Arabia	0.28	Sadiq and Mian[53]
Jeddah, Saudi Arabia	0.90	Waleed *et al.*[54]
Riyadh, Saudi Arabia	1.43	Present study
Rural		
Hemby, UK	0.034	Yaaqub *et al.*[55]
Kiel, FRG	0.053	Schneider[56]
North Sea	0.096	Baeyens and Dedeurwaerder[27]
Riyadh, Saudi Arabia	0.280	Present study

Comparison of atmospheric Pb of Riyadh with those from other locations

To put these results of Pb in a wider context, comparison with the results of other surveys was thought necessary. Comparative statement of Pb levels (Table-4) indicates that Pb concentrations obtained during the present investigation are in general significantly higher in the Riyadh environment especially along King Fahad road and the industrial workshops area. This study has shown that airborne Pb concentrations in Riyadh city might pose a potential health hazard particularly where the traffic density is high.

Conclusions and recommendations

This investigation has illustrated that the main sources of atmospheric metal pollutants in Riyadh city were automobile exhaust emissions and industrial activities in the first industrial city and the industrial workshops area. It is concluded that the concentration of airborne Pb in Riyadh city is related to traffic intensity.

Finally, Pb will have a relative high residence time in the warm dry atmosphere of Riyadh and this, coupled with the great mobility of dust, will increase the exposure of human respiratory pathways to metal contamination. On the other hand, none of the vegetable and fruit products consumed within the city of Riyadh are grown there. Therefore, the route of exposure to the metal burden in the Riyadh environment is likely to be through respiration processes rather than food consumption.

In the light of this work, the following recommendations are made:

- It is recommended that traffic engineers and planners use the information provided by this work regarding the metal pollutant levels along Riyadh's roads in the development and modification of the city's network.
- It is recommended that people spending long hours near roads to stay at least 50 metres away from the road edge.
- Since high Pb concentrations were recorded, it is suggested that measures be adopted to control Pb contamination in the city, such as reducing the Pb content in petrol, and the introduction of lead-free gasoline.
- The industrial workshops area due to highly industrial activities produces large amont of metal pollutants and since most of the workshops involve open-air work, no means have been used to reduce these pollutants. Such pollutants harm workers and affect people in the surrounding areas due to translocation of these pollutants by the winds. Therefore, it is recommended that measures to control their release be adopted immediately.

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